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Stealth metamaterial objects characterized in the far field by radar cross section measurements

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Reflection spectra and radar cross sections (RCS) at terahertz frequencies are measured on structures incorporating absorbing metamaterials. Reduction of the RCS by the factor of 375 at the resonant frequencies is observed.

Introduction

Absorbing metamaterials (MM) offer the exciting possibility of near-unity absorption at specific resonance frequencies where the characteristic impedance Z(ω) is designed to match the free-space impedance and the imaginary part of the refractive index κ(ω) is as high as possible. Such materials have been realized in the form of thin, flexible metalized films of polyimide (PI) [1]. Terahertz time-domain spectroscopy confirmed the very high absorption at the resonance frequencies.

The real-world applications of such absorbing materials are plentiful, including suppression of unwanted reflections, stealth operation, and frequency-selective filters for chemical imaging applications. Here we apply a near-unity absorbing MM as a way to reduce the radar cross section of an object, and consider the real-life situation where the probe beam is significantly larger than the MM film and the object under investigation. Thus we need to be concerned not only about the intrinsic properties of the MM film, but also on scattering from edges of the object and other disturbances.

Experimental setup

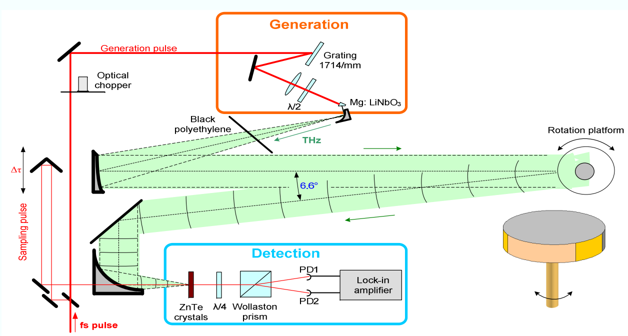


Fig. 1. Schematic diagram of the THz radar cross section setup.

THz generation by optical rectification in 1% MgO doped stoichiometric $LiNbO_3$ with tilted wavefront method [3]

- Collimated and 20x magnified THz beam with FWHM at the target of 7.3 cm
- Bistatic configuration with 6.6° angle between incident and scattered beam
- THz detection by free space electro-optic sampling

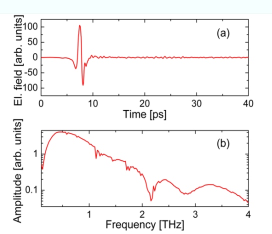


Fig. 2. (a) Terahertz waveform reflected from 170mm-diameter metal flat disk (b) Amplitude spectrum of the generated terahertz radiation

Metamaterial samples

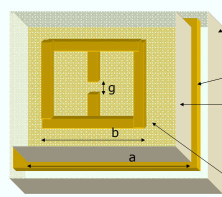
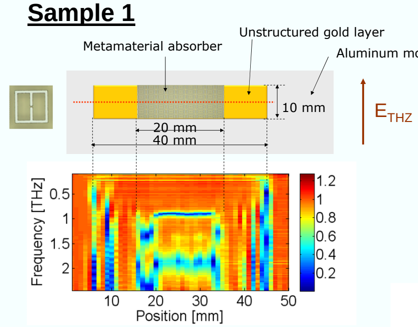


Fig. 3. Terahertz metamaterial absorber consisting of 2D array of split ring resonators. Unit cell size a: 36μm, size of the split ring resonator b: 26μm, capacitor gap 2μm.

Metamaterial samples – reflectivity measurements

Sample 1



- Strong reduction of reflectivity of the sample at the metamaterial LC resonance frequency 0.887 THz to only 0.045
- Reduction of reflectivity is achieved by impedance matching between vacuum and the front layer of metamaterial

Fig. 4. (Top left) Geometry of the metamaterial unit cell, (top right) geometry of metamaterial sample, (bottom) frequency resolved reflectivity along the sample 1(red line) measured using THz raster scanner.

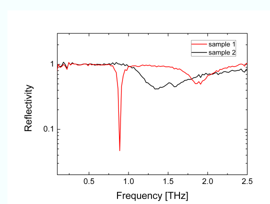
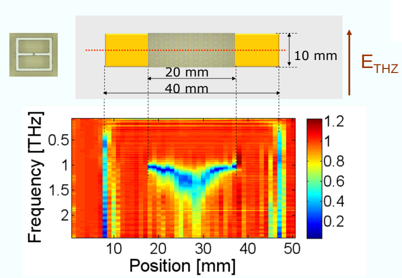


Fig. 5. Reflectivity of the central parts of the samples.

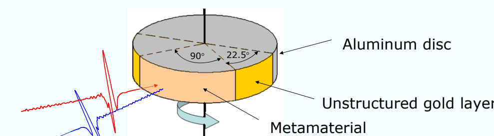
Sample 2



- Broad decrease of reflectivity in the frequency range 1.05 - 1.35 THz
- Non uniform properties of the sample

Fig. 6. Frequency resolved reflectivity along the sample 2.

RCS measurements on metamaterials



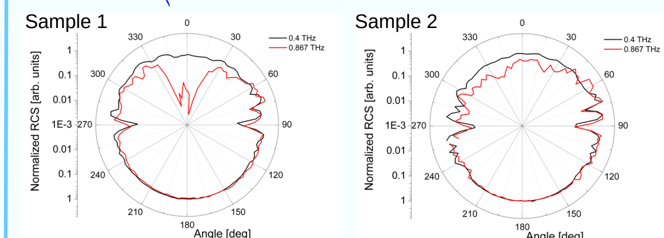


Fig. 7. Normalized frequency resolved radar cross sections for samples 1 and 2 at frequency 0.4 and 0.867 THz.

- Maximum decrease of normalized RCS for 0.867 THz to 0.0027 (factor of 375)
- Strong scattering resulting in high noise at the directions of interfaces
- RCS decreased in 70% of angular range corresponding to the metamaterial presence

RCS measurements on scale models

The frequency-averaged radar cross section can be introduced:

$$RCS = \pi a^2 \cdot \frac{\int_0^T \left|E_{object}(t)\right|^2 dt}{\int_0^T \left|E_{cal}(t)\right|^2 dt - \int_0^T \left|E_{bg}(t)\right|^2 dt},$$

where is $E_{object}(t)$the detected electric field from the scattering object, $E_{cal}(t)$ the electric field scattered by the calibrated spheres of radar cross section of πa^2, and the $E_{bg}(t)$ represents background noise. All the quantities can be Fourier transform and a frequency resolved radar cross section can be obtained.

$$RCS(\omega) = \pi a^2 \cdot \frac{\left|E_{object}(\omega)\right|^2}{\left|E_{cal}(\omega)\right|^2 - \left|E_{bg}(\omega)\right|^2},$$

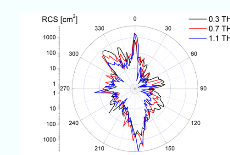


Fig. 8. Frequency-resolved azimuthal RCS of a metal model of the fighter aircraft F-16 at frequencies 0.3, 0.7 and 1.1 THz. The presented data are averaged within a frequency interval of +/-20GHz.

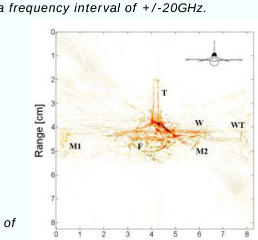


Fig. 9. Cross section of the scale model of the F-16 aircraft reconstructed using the filtered back projection algorithm. Letter marks indicate positions of different scattering parts of the airplane model: wing tips (WT), wing (W), tail (T), fuselage (F) and missiles (M1, M2).

References

[1] H. Tao *et al.*, Phys. Rev. B. **78**, 241103(R) (2008)
[2] K. Iwaszczuk *et al.*, Opt. Express **18**, 26399-26408 (2010)